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Polarization properties of chiral-core planar waveguides

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Abstract

A new form for the modal eigenvalue equations of chiral-core planar waveguides provides insight into the transition, with increasing chirality, from TE/TM (transverse electric/magnetic) modes in the achiral case to nearly right-handed and left-handed circularly polarized modes. Dramatic variation of the polarization eccentricity with thickness and frequency is discussed.

Polarization Properties of Chiral Core Planar Waveguides

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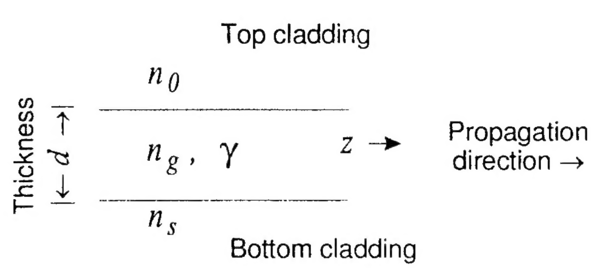
U.S. Navy, NAWCAD

EO Sensors Division, Patuxent River, MD

OTF2001
15-17 October 2001

Chiral Core Optical Waveguides



ISOTROPIC CHIRAL MEDIUM

Constitutive Relations (Drude-Born-Federov)

$$\boxed{\vec{D} = \varepsilon(\vec{E} + \gamma\,\nabla \times \vec{E}) \qquad \vec{B} = \mu(\vec{H} + \gamma\,\nabla \times \vec{H})}$$

Bohren's Decomposition

$$\boxed{\vec{E} = \frac{1}{2}(\vec{F}^{+} + \vec{F}^{-}) \qquad \vec{H} = \frac{1}{2i}\sqrt{\frac{\varepsilon}{\mu}}(\vec{F}^{+} - \vec{F}^{-})}$$

Wave Equation

$$\boxed{\nabla^2 \vec{F}^{\pm} + (k_0 n_{\pm})^2 \vec{F}^{\pm} = 0}$$

Eigenmodes in bulk material circularly polarized

$$\boxed{\vec{F}^{\pm} = \vec{E}_0 e^{i(k_0 n_{\pm} z - \omega t)}(\hat{x} \pm i\hat{y})}$$

Refractive indices for RH and LH waves

$$\boxed{n_{\pm} = \frac{n_g}{1 \pm \delta} \qquad \delta = k_0 n_g \gamma \qquad n_g = \sqrt{\frac{\varepsilon}{\varepsilon_0}} \qquad k_0 = \frac{2\pi}{\lambda}}$$

Rotatory Power

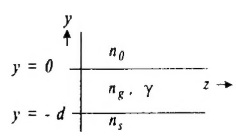
$$\boxed{\rho = \frac{\pi(n_{-} - n_{+})}{\lambda} \approx k_0 n_g \delta}$$

A. Lahtakia, V.K. Varadan, and V.V. Varadan, Time-Harmonic Electromagnetic Fields in Chiral Media, Lecture Notes in Physics Series 335 (Springer-Verlag, Berlin, 1989).
I.V. Lindell, A.H. Sihvola, S.A. Tretyakov, A.J. Viitanen, Electromagnetic Waves in Chiral and Bi-isotropic Media, (Artech House, Norwood, MA, 1994).

Modes in Chiral Asymmetric Waveguide

W. N. Herman, accepted *J. Opt. Soc. Am. A*

$$\vec{F}^{\pm}(y,z) = \vec{\Psi}^{\pm}(y)\exp(-ik_0 n_{eff} z)$$



Modal equations: (3 equations to be solved simultaneously for n_{eff}, g, h)

$$\boxed{\begin{aligned} u^{\pm} d &= \cot^{-1}\left(\sigma_0^{\pm}\frac{r_0 \pm g}{1 \pm g}\right) + \cot^{-1}\left(\sigma_s^{\pm}\frac{r_s \pm h}{1 \pm h}\right) + m^{\pm}\pi \\ h(g, n_{eff}) &= \frac{(Sr_0^{+} - Sr_0^{-}) + (S_0^{+} + S_0^{-})g}{(Sr_0^{+} + Sr_o^{-}) + (S_0^{+} - S_0^{-})g} \end{aligned}}$$

$$S_0^{\pm} \equiv \sigma_0^{\pm}\sin(u^{\pm}d) - \cos(u^{\pm}d)$$

$$Sr_0^{\pm} \equiv r_0\sigma_0^{\pm}\sin(u^{\pm}d) - \cos(u^{\pm}d)$$

$$\sigma_0^{\pm} \equiv (1 \pm \delta)\frac{u^{\pm}}{v}, \quad \sigma_s^{\pm} \equiv (1 \pm \delta)\frac{u^{\pm}}{w}, \quad r_0 \equiv \frac{n_0^2}{n_g^2}, \quad r_s \equiv \frac{n_s^2}{n_g^2}$$

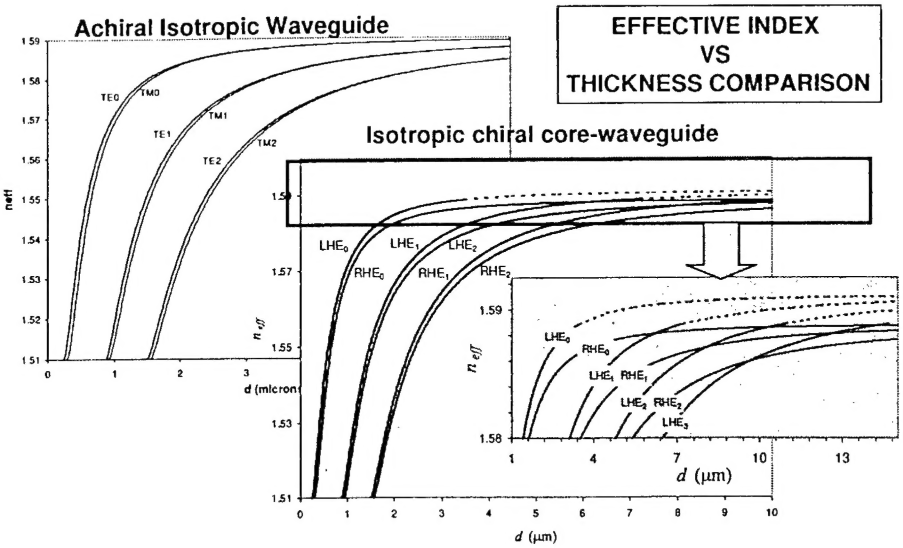
$$u^{\pm} \equiv k_0\sqrt{n_{\pm}^2 - n_{eff}^2}, \quad v \equiv k_0\sqrt{n_{eff}^2 - n_0^2}, \quad w \equiv k_0\sqrt{n_{eff}^2 - n_s^2}$$

$$n^{\pm} = \frac{n_g}{1 \pm \delta}$$

Parameters g, h determine eccentricity of polarization ellipse for transverse E-field:

$$\left.\frac{E_y}{E_x}\right|_{y \geq 0} = i\frac{n_{eff}}{n_g}\frac{1}{g} \qquad \left.\frac{E_y}{E_x}\right|_{y \leq -d} = i\frac{n_{eff}}{n_g}\frac{1}{h}$$

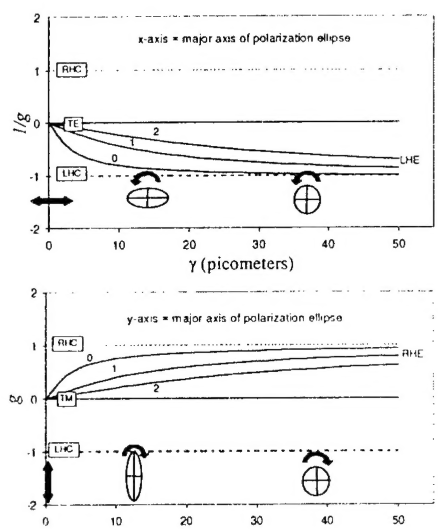
EFFECTIVE INDEX VS THICKNESS COMPARISON



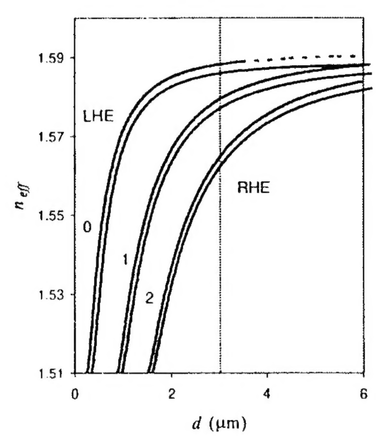
- **Achiral:** *neff*(TE)-*neff*(TM) → 0 as thickness increases
  - **Chiral:** *neff*(LHE)-*neff*(RHE) → $n^- - n^+$ as thickness increases

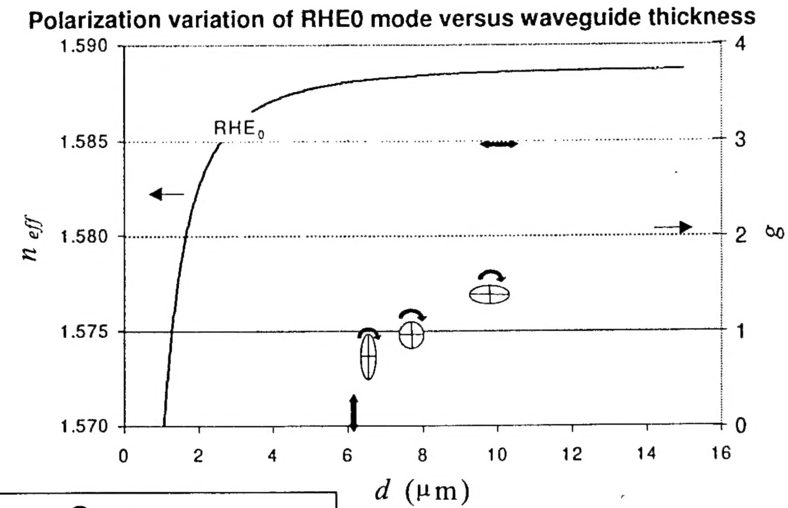
Transition; TE/TM ⇒ LHC/RHC

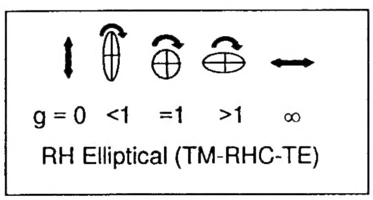
3 micron thick film, n_0=1, n_s=1.51



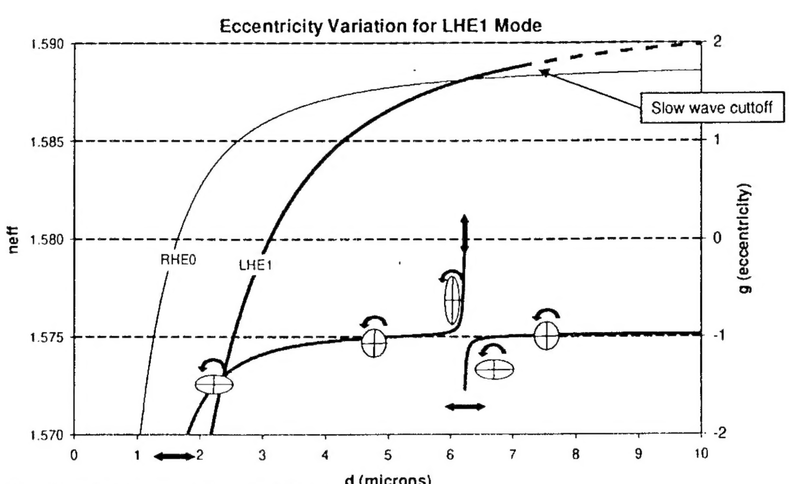
Effective Index vs Thickness

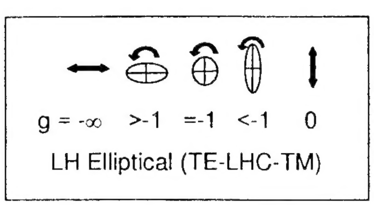




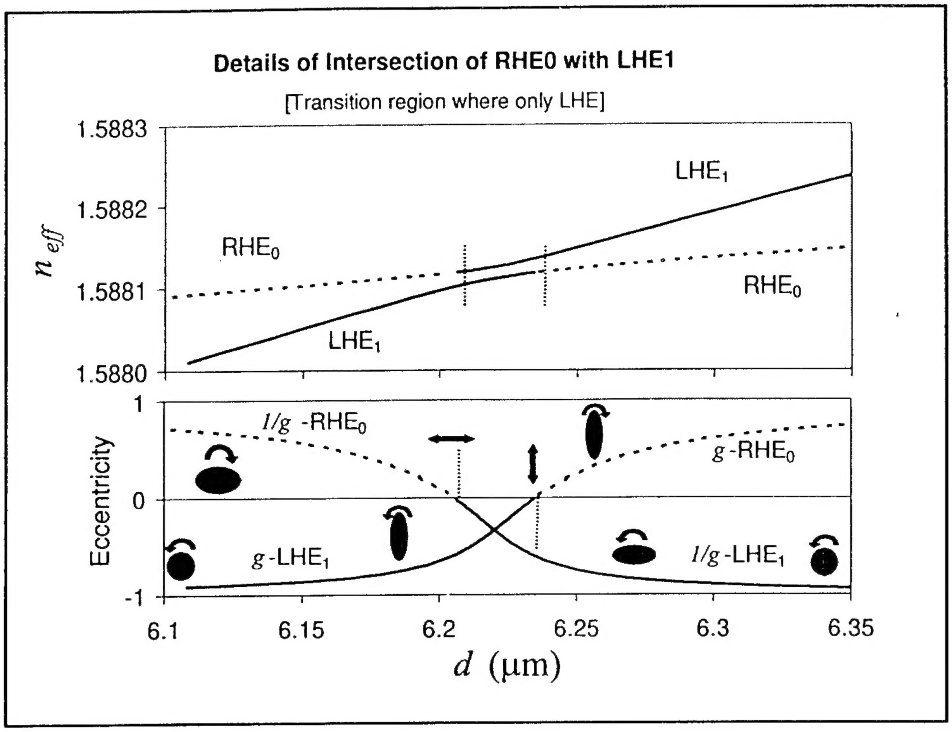


Dramatic change in polarization at mode intersections

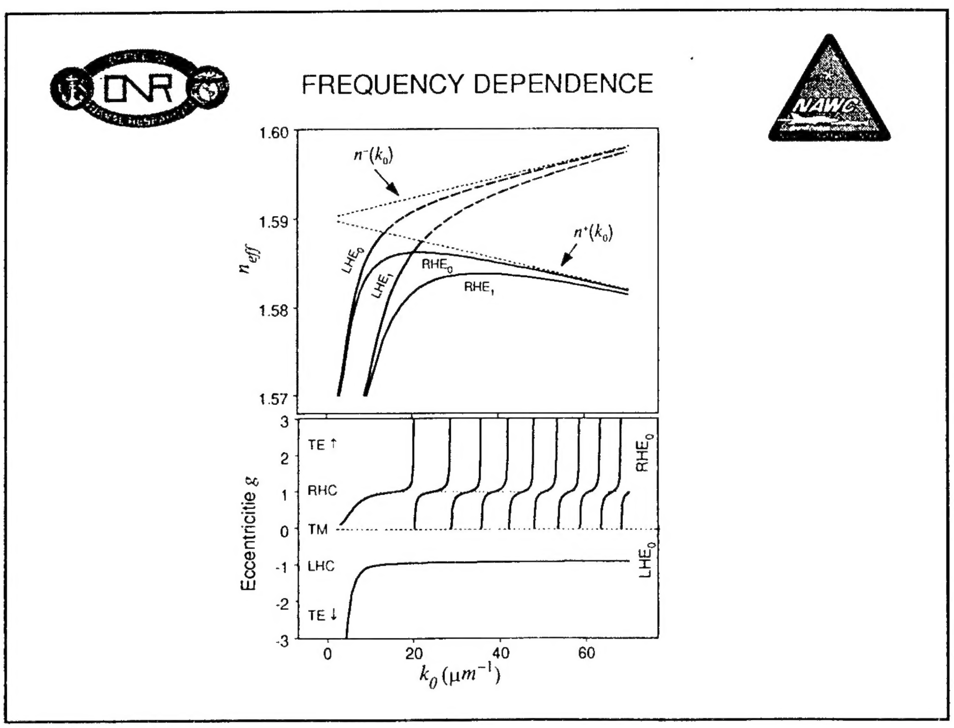




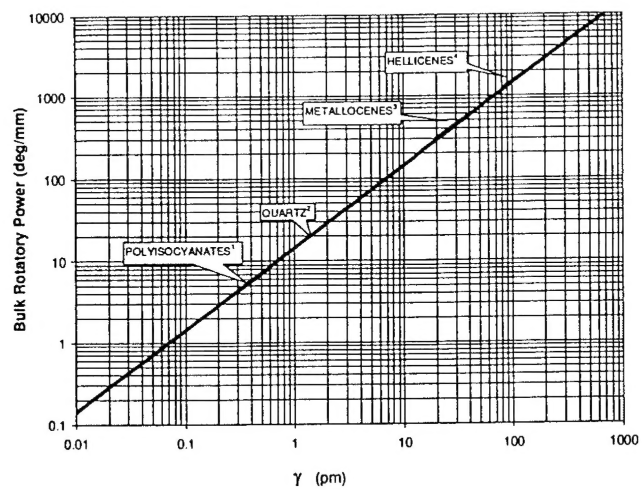
- **Dramatic change in polarization at mode intersection**
- **Polarization fairly constant past slow wave cutoff**



Details of Intersection of RHE0 with LHE1
[Transition region where only LHE]
1.5883
1.5882
1.5881
1.5880
n_{eff}
RHE$_0$
LHE$_1$
RHE$_0$
LHE$_1$
1
0
-1
Eccentricity
$1/g$ -RHE$_0$
g-RHE$_0$
g-LHE$_1$
$1/g$-LHE$_1$
6.1
6.15
6.2
6.25
6.3
6.35
d (μm)



FREQUENCY DEPENDENCE
1.60
1.59
1.58
1.57
n_{eff}
$n^-(k_0)$
$n^+(k_0)$
LHE$_0$
LHE$_1$
RHE$_0$
RHE$_1$
3
2
1
0
-1
-2
-3
Eccentricitie g
TE ↑
RHC
TM
LHC
TE ↓
RHE$_0$
LHE$_0$
0
20
40
60
$k_0\,(\mu m^{-1})$



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